Species	UKBAP	LBAP
Small Heath	UKBAP	
Grayling	UKBAP	

Table 2. Species of butterfly and moths recorded in Glasgow as part of the BIG project which had a conservation listing.

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Urban Biodiversity: Successes and Challenges: Bat activity in urban green space

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ABSTRACT

Green spaces within urban areas can be important for ameliorating the impacts of urbanisation on biodiversity, and can hold relatively rich wildlife communities. In contrast to some other taxa, relatively little is known about the ecology of bats in urban environments, and in this study we aimed to identify site-specific and wider landscape features that influence bat foraging activity within areas of urban green space. Bat activity primarily comprised *Pipistrellus pygmaeus* and was detected at 86% of parks surveyed. The presence of water bodies and woodland in urban parks increased bat foraging activity by a factor of 3.2 and 1.7 respectively. Data presented in this study indicate that, for this species, habitat within a site may be more important than the level of urbanisation or woodland cover in the surrounding landscape.

INTRODUCTION

Urbanisation and green space

Urbanisation by expanding human populations reduces native biological diversity by decreasing the amount and quality of habitat available for wildlife, and by the fragmentation of remaining habitats (e.g. Marzluff *et al.,* 1998). It has been estimated that currently 50% of the world's population live in areas classed as urban, a figure set to increase along with the human population (United Nations, 2008). Urban development will therefore continue to grow, resulting in further losses of natural and semi-natural habitats, and increasing pressure on remaining habitat fragments which may suffer increasing isolation and deterioration in quality

(Marzluff and Ewing, 2001; Chamberlain *et al.*, 2007). Green spaces within urban areas (e.g. parks, domestic gardens) typically consist of small, highly disturbed or modified patches of vegetation distributed within a matrix of urban development such as buildings and associated infrastructure. Whilst several studies have shown that species diversity for several taxa decreases along the rural-urban gradient (e.g. Sadler *et al.*, 2006; Duchamp and Swihart, 2008), green spaces can nevertheless ameliorate the impacts of urbanisation on biodiversity, and may hold relatively rich wildlife communities (e.g. Chamberlain *et al.*, 2007; Davies *et al.*, 2009). Factors commonly found to influence the abundance and diversity of several taxa (birds, mammals, invertebrates) include the size, habitat quality and structure of green spaces, although the quality and proximity of suitable habitat in the wider landscape can also be important (e.g. Sadler *et al.*, 2006; Baker and Harris, 2007; Chamberlain *et al.*, 2007). Clergeau *et al.*, (2001) and Angold *et al.*, (2006) argue that appropriate management within areas of urban green space areas can benefit many avian and invertebrate species regardless of the surrounding landscape, and such actions may be far easier to implement. However, the relative importance of local habitat versus the wider landscape is likely to vary markedly between species depending on their ecological requirements and mobility.

Status and conservation of bats in Europe

There is evidence that many bat species in Europe have undergone large population declines during the 20th century, driven by the loss of foraging and roosting habitat. A UK-wide bat survey in the 1990s found that habitats favoured by foraging bats were undergoing rapid rates of loss within the UK, and suggested that this may be limiting bats in some areas (Barr *et al.*, 1993; Walsh *et al.*, 1996). Although it remains the most abundant and widespread bat genus in the UK, estimates from the Annual Bat Colony Survey in the UK suggest a decline of over 60% between 1978 and 1993 for *Pipistrellus* spp. (Hutson, 1993). The species *Pipistrellus pipistrellus* was only recently recognised as two separate species, *P. pipistrellus* and *P. pygmaeus* (International Commission on Zoological Nomenclature, 2003), so it is not known whether this decline has affected both species equally.

In order to sustain bat populations, urban areas need to provide both roosting and foraging sites, and routes which allow bats to commute between the two. Some bat species now commonly use buildings as maternity roosts, and exploit foraging opportunities provided by man made structures such as streetlamps and sewage works that are associated with high insect densities (Rydell, 1992; Altringham, 2003; Park and Cristinacce, 2006). Several studies have suggested that urban environments may have a positive role to play in resource availability for bats (e.g. Avila-Flores and Fenton, 2005; McDonald-Madden *et al.*, 2005; Haupt *et al.*, 2006), particularly in landscapes dominated by intensive agricultural land use, which studies have repeatedly found are avoided by bats (Walsh and Harris, 1996; Gehrt and Chelsvig, 2003). There appear to be marked species-specific responses to urbanisation, however, with other species strongly avoiding built up areas (e.g. Kurta and Teramino, 1992; Waters *et al.*, 1999; Lesińki *et al.*, 2000).

Understanding how different species use urban environments and how habitat management and urban planning can promote population persistence is critical to their conservation. The aim of this study was therefore to identify site-specific and wider landscape features (e.g. woodland connectivity, urbanisation) that influence bat activity within areas of urban green space.

MATERIALS AND METHODS

Study sites

Glasgow is the largest city in Scotland (UK), with the Greater Glasgow conurbation covering an area of 369km^2 with a population of approximately 1.2 million people. Over 20% of the area of Greater Glasgow is green space; including 74 parks and other potentially important features such as river corridors, woodlands, cemeteries and communal gardens (Humphries *et al.*, 2009). Other than two very large sites (>140 ha), green space areas owned by Glasgow City Council (GCC) range from 1.5 – 68.4 ha (mean 18.2). A total of 29 sites owned and managed by GCC were surveyed for bat activity between 31 May and 11 July 2007 (Table 1). Sites were chosen randomly whilst ensuring they were a minimum of 1km apart and spanned a range of sizes (mean 24.3 ± 14.9; range 6.2 – 53.2 ha).

Monitoring bat activity

Point counts were used to quantify bat activity. At each park 10 minute recordings were made at between two and six locations depending on the size of the park (across parks, an average of four point counts were recorded). Each point location was chosen using randomly-generated xy coordinates but omitting areas of open water within the park and ensuring a minimum distance of 30m between points. On each survey night, one of four geographical areas of Glasgow (NE, NW, SE, SW) was chosen randomly, and between one and four parks were surveyed, again in random order, with each park being surveyed once. Within a night, all point counts were conducted within 2 h 15 minutes of each other, the first starting 45 min after sunset. At the start of each count air temperature was measured to the nearest 0.1°C and wind speed was estimated using the Beaufort scale. Counts were only conducted in dry weather where the temperature at dusk exceeded 10°C and the strength of the wind did not exceed Beaufort 3 (since strong winds influence both insect distribution and detectability of bat calls).

Sound recording and analysis

A frequency division bat detector (Batbox Duet, Stag Electronics; frequency response 17-120kHz) was connected to a MiniDisc (Sony MZ-R909; frequency response ± 3dB 20Hz – 20kHz) and a continuous recording made for each point count onto a recordable MiniDisc. Frequency division is a broad-band system that records all frequencies continuously, and is sufficient for distinguishing between the genera *Myotis* and *Pipistrellus*, and between the *Pipistrellus* species (e.g. Vaughan *et al.*, 1997a; see sound analysis). We analysed recordings using BatSound v3.31 (Pettersson Elektronik AB, Uppsala, Sweden), with a sampling frequency of 44.1kHz with 16 bits per sample, and a 512 pt. FFT with Hanning window). One bat pass was defined as a continuous sequence of at least two echolocation calls from a passing bat (Fenton, 1970; Walsh *et al.*, 1996).

Three genera of bat occur in the area where this study was conducted; *Pipistrellus*, *Myotis* and *Plecotus* (Richardson, 2000), although *Plecotus* is rarely recorded due to its quiet echolocation calls. Unfortunately, problems with the recording equipment meant that for all but seven parks (representing 25% of the point counts) recordings were made in mono (heterodyne) rather than stereo (heterodyne and frequency division. Analyses were therefore conducted on the number of bat passes per point count. Terminal feeding buzzes emitted when attempting prey capture were also counted and provide a measure of foraging effort.

Habitat availability within, and surrounding, urban parks

Habitat structure within the parks was fairly simple consisting largely of a mixture of improved grassland, mixed woodland and shrubs. All but one park had some mixed woodland on site, although there was considerable variation in the amount among parks (0.3 - 45ha). Of the parks surveyed, 21 had still (> 3m width) or running water (> 1m width) present. Habitat within 30m of each recording point was categorised according to the presence of woodland and still or running water. Of 111 point counts made, 31 were adjacent to water (i.e. within 30m), 50 were adjacent to woodland, 12 were adjacent to both water and woodland and 42 were made within grassland with no water or woodland nearby.

The landscape analysis was performed using data from OS MasterMap Topography Layer (Digimap Ordnance Survey® Collection). We used ArcGIS 9.2 to create buffers of 1 km radius around the centre of each park and reclassify the feature classes from the topography layers into five categories (hereafter referred to as habitat classes). These were: 1) urban areas (buildings, structures, roads and parking areas); 2) urban gardens (urban land not covered by buildings or structures); 3) grassland and scrub; 4) woodland (coniferous, deciduous and mixed woodland, and areas covered by scattered trees); 5) water (inland and tidal water). A 6th category (called "other") included features that didn't fall into any of the 5 previously mentioned habitat classes, but its proportion was less than 4% in all cases. Because the 1 km radius was taken from the centre of the park rather than the location of individual points, the proportion of the 3.14 km^2 circle that lies outside the park varies between parks, although this variation is relatively small (non-park area: 83-98%). We then used the software package Fragstats 3.3 to calculate a selection of different landscape metrics for each habitat class within the 1 km buffer including the proportion of land covered, the number of patches, mean patch area, largest patch, total edge density, area-perimeter ratio and Euclidean nearest neighbour distance (ENN distance is the shortest straight-line distance between the focal patch and its nearest neighbour of the same class; McGarigal *et al.*, 2002).

The proportions of different habitat categories within a 1km radius of a park are not independent since all must sum to 1. Our purpose for including information about the habitat surrounding each park as potential explanatory variables in the model was to assess how bat activity may be influenced by levels of urbanisation and proximity of habitats considered important for many bat species, for example woodland. We focused, therefore on the proportion of urban and woodland habitat, and the mean ENN distance among water bodies within a 1km radius of the centre of each park. The size of the park was significantly positively correlated with the proportion of woodland within the 1 km buffer (t_{27} = 2.70, p = 0.012, r^2 = 0.21), and % woodland cover was weakly negatively correlated with % urban cover (t_{27} = -2.05, p = 0.05, r^2 = 0.13) but neither of these was sufficiently strong to cause problems with multicollinearity. There was no correlation between % urban cover and the size of the park (t_{27} = 0.23, p = 0.76, r^2 = 0.0019). Percentage woodland and urban cover were arcsine square root transformed prior to analysis.

There are many different metrics that can be calculated to assess the composition and configuration of habitat patches within a landscape, and therefore potentially a great many potential explanatory variables. We minimised the number of potential variables describing the configuration of woodland patches within the surrounding landscape as the proportion of woodland within a 1km radius of each park correlated strongly with several measures commonly used to assess isolation of that habitat (McGarigal *et al.*, 2002). For example, proportion of woodland was strongly correlated with both edge density (t_{27} = 4.51, p = 0.0001, r^2 = 0.43), and weighted-mean ENN distance (t_{27} = -3.78, p = 0.0008, r^2 0.35).

Data analysis

All statistical analyses were conducted using the R computing environment (version 2.8.1, R Development Core team, 2008). To assess the influence of habitat features and the surrounding matrix on bat activity in urban green space, we fitted a Generalised Linear Mixed Effects model with quasi-poisson errors using the number of bat passes at each location (n=111), as the dependent variable. The following were included in the starting model as potential explanatory variables:

the presence or absence of a water body or woodland adjacent to each point count (within 30m) were included as fixed factors; the order in which the points were surveyed (i.e. to account for variation of activity with time of night), the proportion of woodland and urban cover, and the mean ENN distance between water bodies within a 1km radius of the centre of the park, the size of park, wind speed, temperature (linear and quadratic terms) were covariates. A two way interaction between park size and each of the landscape metrics was also included. Park was a random factor used as a grouping variable. The model was carried out in a stepwise fashion, with the least significant of the explanatory variables being removed at each step in an effort to determine which of these variables had the most significant effect.

RESULTS

Bat activity

A total of 852 bat passes was detected during 18.5 hours of recording during the study. On average, 14.7% of bat passes had feeding buzzes and evidence of feeding activity was detected at 62% (18/29) parks. There was a significant positive correlation between the number of bat passes and feeding buzzes per park (Spearman rank $r_{s29} = 0.79$, $p < 0.0001$), suggesting that the use of bat passes is a reasonable measure of foraging activity.

For the seven parks (28 point count locations) at which bat passes could be assigned to species level (see Methods), 128 of 160 (80%) of identified *Pipistrellus* passes were attributable to *P. pygmaeus*. Total bat activity within urban parks was significantly higher adjacent to water bodies or areas of woodland; based on differences in the adjusted median values, the presence of water bodies and woodland increased bat activity by a factor of 3.2 and 1.7 respectively (Table 2, Figs. 1 and 2). The final model explained 56% of the variation in activity among point counts. There were no significant interactions between the size of park and the surrounding landscape variables (proportion of urban, proportion of woodland, mean ENN distance between water bodies within a $1km^2$ radius around each park), and none of the landscape variables had a significant influence on bat activity on their own.

In this study wind speed correlated positively with bat activity (Table 2) although this relationship is entirely reliant on the data point with the highest bat activity and, if removed, wind speed becomes non-significant. The remaining variables in the model, however, are all retained.

DISCUSSION

The presence of both water bodies and woodland in urban parks resulted in significantly increased bat activity, with the effect of water being the most marked. This is likely to be because the majority of bat passes recorded during these surveys were of *P. pygmaeus* which, of the two most common pipistrelle species in the UK, is particularly associated with riparian habitats (Vaughan *et al.,* 1997b; Nicholls and Racey, 2006; Sattler *et al.,* 2007). The importance of water bodies within urban green space for birds has recently been highlighted by the Biodiversity In Glasgow project, co-ordinated by the British Trust for Ornithology (Humphries *et al.,* 2009). Between five and 61 bird species were recorded within urban green spaces in Glasgow, with sites containing water bodies having an average of five more species than those lacking water.

Previous studies have shown the importance of deciduous or mixed woodland for foraging bats (e.g. Walsh and Harris, 1996; Johnson *et al.,* 2008), and areas with higher proportions of well connected woodland might have been expected to have had higher levels of bat activity as found by Gehrt and Chelsvig, 2003. In this study, however, although woodland adjacent to recording sites had a positive effect on levels of bat activity (largely *P. pygmaeus*), the amount and connectivity of woodland at a larger scale did not.

Previous work has indicated that species respond differently to urbanisation which, given the marked differences in roosting and foraging ecology among bat species, is not surprising. Gehrt and Chelsvig (2004) found positive associations between urban indices and activity of *Eptesicus fuscus, Lasiurus borealis and L. noctivagans.* Other species, however, appear to largely avoid urban areas (e.g. *Nyctalus leisleri* – Waters *et al.,* 1999; *Myotis sodalis* – Sparks *et al.,* 2005) or are otherwise sensitive to features associated with urbanisation such as street lighting (e.g. *Rhinolophus hipposideros* – Stone *et al.,* 2009). Duchamp and Swihart (2008) identified two groups of bat species whose populations showed opposite trends along urban and forest gradients. Species that responded negatively to urban development were those requiring tree cavities for roosting and a wing morphology adapted to flight in cluttered environments such as woodland (ie. low wing loading), whereas the opposite was true for species that responded positively to urbanisation. These predictions fit well with our findings for *P. pygmaeus,* the most frequent species recorded during this study, which is commonly associated with building roosts and adapted to flight in relatively open environments. It might be expected that the two *Myotis* spp. commonly found in Scotland would react differently to urbanisation: *M. daubentoni* is also associated with riparian habitats but typically roosts in tree cavities or within the stonework of bridges, and *M. nattereri*, also a tree rooster, forages largely in woodland habitats (Altringham 2003).

Data presented in this study suggests that, for *P. pygmaeus*, the habitat within a site may be more important than the surrounding landscape as Gilbert (1989) suggested may be the case for highly mobile species within urban environments. That the size of park was not an influential factor on *P. pygmaeus* activity suggests that even small areas of urban green space can provide valuable foraging opportunities for bats able to adapt to urbanised landscapes, provided there is suitable habitat (ie. water bodies and woodland) within the site. For other species, however, a wider landscape-approach, such as increasing woodland cover both within urban parks and in the surrounding matrix to link foraging areas, is likely to be necessary.

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Site name	Latitude	Longitude	Size (ha)	Date surveyed	Surrounding habitat		
					% urban	% woodland	Mean ENN distance water[a]
Auchinlea Park	55° 52' 16.96"	-4° 8' 1.81"	29	11/07/2007	24.6	5.5	395.0
Cardonald Park	55° 51' 27.26"	-4° 20' 55.78"	7	18/06/2007	32.6	3.3	57.4
Cardowan Moss Woodland	55° 52' 48.28"	-4° 9' 1.09"	45	10/07/2007	16.2	16.8	57.1
Cleddans Burn	55° 54' 51.80"	-4° 23' 9.14"	15	04/06/2007	14.6	9.4	40.1
Cowlairs Park	55° 52' 42.12"	-4° 14' 46.12"	17	06/06/2007	30.7	2.4	5.6
Cranhill Park	55° 51' 55.55"	-4° 9' 55.72"	10	17/06/2007	24.2	4.8	2.5
Crookston Woods	55° 50' 16.15"	-4° 20' 51.49"	10	09/07/2007	22.2	8.5	5.4
Dawsholm Park	55° 53' 48.65"	-4° 18' 57.62"	33	04/07/2007	24.3	17.8	8.0
Early Braes	55° 51' 5.64"	-4° 8' 9.41"	10	03/07/2007	20.7	4.6	26.9
Elder Park	55° 51' 48.51"	-4° 19' 19.24"	14	18/06/2007	32.4	3.8	129.0
Garscadden Burn	55° 54' 30.84"	-4° 21' 41.44"	23	19/06/2007	23.8	2.8	8.0
Garscadden Woods	55° 55' 9.96"	-4° 21' 26.53"	25	04/06/2007	16.4	7.1	18.5
Glasgow Green	55° 51' 5.25"	4° 14' 34.79"	53	08/07/2007	36.7	4.9	754.8
Hogganfield Park	55° 52' 47.17"	-4° 10' 4.35"	46	17/06/2007	16.6	12.5	40.7
Househill Park	55° 49' 13.64"	-4° 21' 45.20"	23	09/07/2007	18.2	8.8	5.6
Kelvingrove Park East	55° 52' 10.59"	-4° 16' 56.68"	36	18/06/2007	38.0	3.8	11.9
Kings Park	55° 48' 55.95"	-4° 14' 27.34"	28	08/07/2007	19.9	5.4	517.7
Knightswood Park	55° 53' 49.48"	-4° 21' 4.37"	20	04/07/2007	19.7	1.5	11.8
Linn Park	55° 48' 19.13"	-4° 15' 34.17"	50	11/06/2007	18.1	11.4	41.5
Maxwell Park	55° 50' 16.93"	-4° 17' 18.77"	8	10/06/2007	24.5	4.4	134.3
Mount Vernon Park	55° 50' 33.21"	-4° 8' 13.38"	6	03/07/2007	17.4	3.6	25.3
Newlands Park	55° 48' 43.51"	-4° 16' 56.04"	6	11/07/2007	23.3	2.0	84.1
Priesthill Park	55° 48' 39.19"	-4° 20' 45.65"	7	09/07/2007	24.2	7.3	8.0
Queens Park	55° 49' 49.00"	-4° 16' 13.88"	45	10/06/2007	30.7	7.2	129.1
Robroyston Park	55° 53' 24.23"	-4° 11' 44.30"	42	11/07/2007	18.9	2.9	163.4
Sandyhills Park	55° 50' 51.60"	-4° 9' 11.90"	9	03/07/2007	22.0	4.0	18.4
Springburn Park	55° 53' 32.17"	-4° 13' 22.65"	31	06/06/2007	22.7	7.8	49.1
Tollcross Park	55° 50' 56.35"	-4° 10' 49.95"	37	03/07/2007	28.1	7.1	23.8
Victoria Park	55° 52' 29.77"	-4° 20' 1.99"	20	04/07/2007	29.8	4.8	170.4

Table 1. Locations and attributes of parks visited and the landscape metrics used in the starting model of bat activity. [a] Mean Euclidean Nearest Neighbour Distance between water bodies (ENN distance is the shortest straight-line distance in metres between the focal patch and its nearest neighbour of the same class).

Source	Degrees of freedom	Parameter estimate	Estimate Standard Error	t value
Adjacent water	1	1.699	0.276	6.613 ***
Adjacent woodland	1	0.383	0.268	1.430 ***
Wind speed	1	0.389	0.260	1.496 ***
Temperature	1	-2.098	0.936	-2.242 ***
Temperature^2	1	0.058	0.0288	2.017 ***
Survey order	1	-0.207	0.103	-2.019 ***

Table 2. Generalised linear mixed-effects model for the effects of habitat and weather variables on bat activity within urban parks in Glasgow City (*** $p < 0.0001$). The sign and size of the parameter estimate (and the error) are used to assess the relative magnitude of the effects of these variables on bat activity.

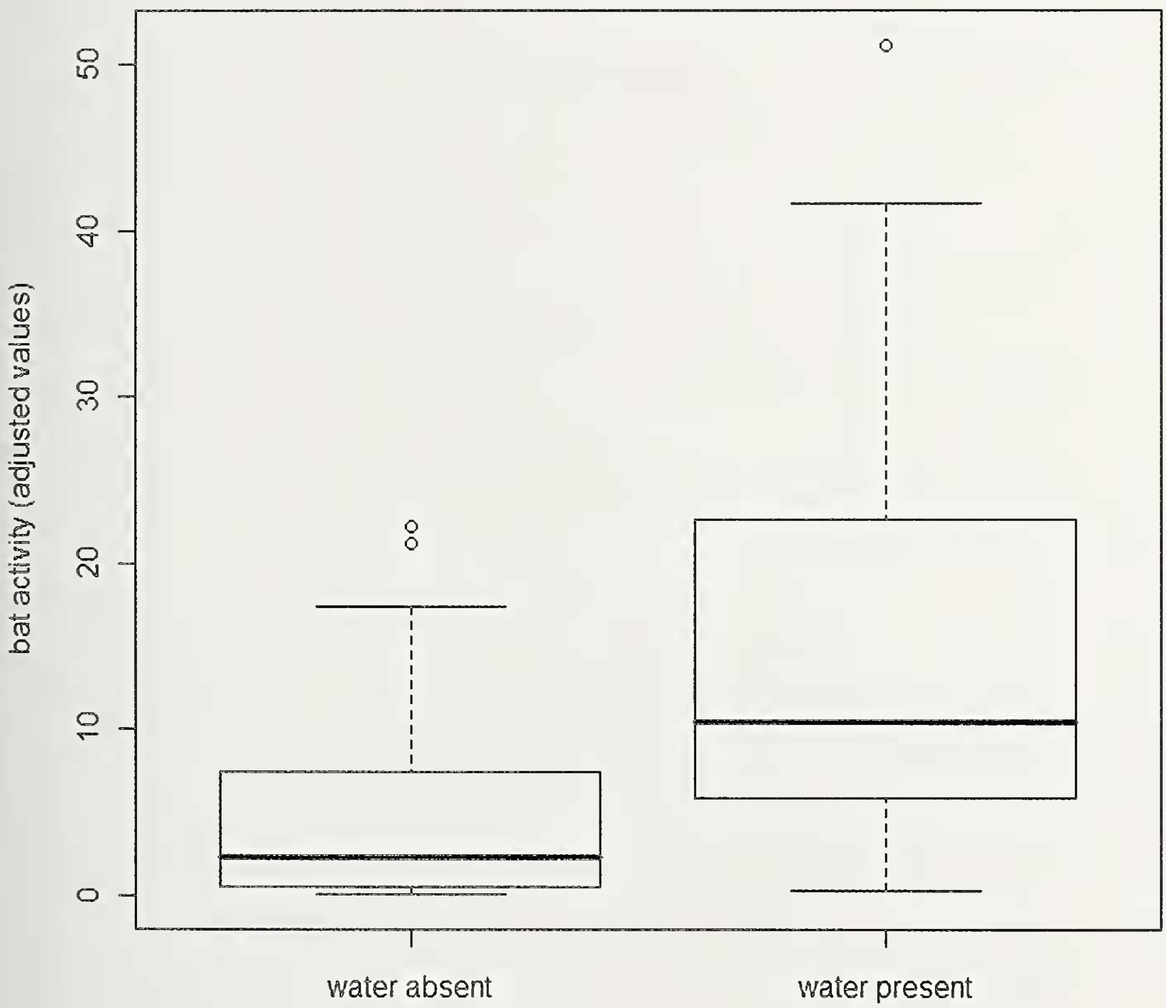

Fig. 1. Adjusted total bat passes at ten-minute point counts adjacent (n=31) and not adjacent (n=80) to water bodies. Values shown are those corrected for explanatory variables in the final model (Table 2). Tukey box plots are used here with boxes representing the location of the middle 50 percent of the data and the upper and lower quartiles, and the whiskers 1.5 x the interquartile range.

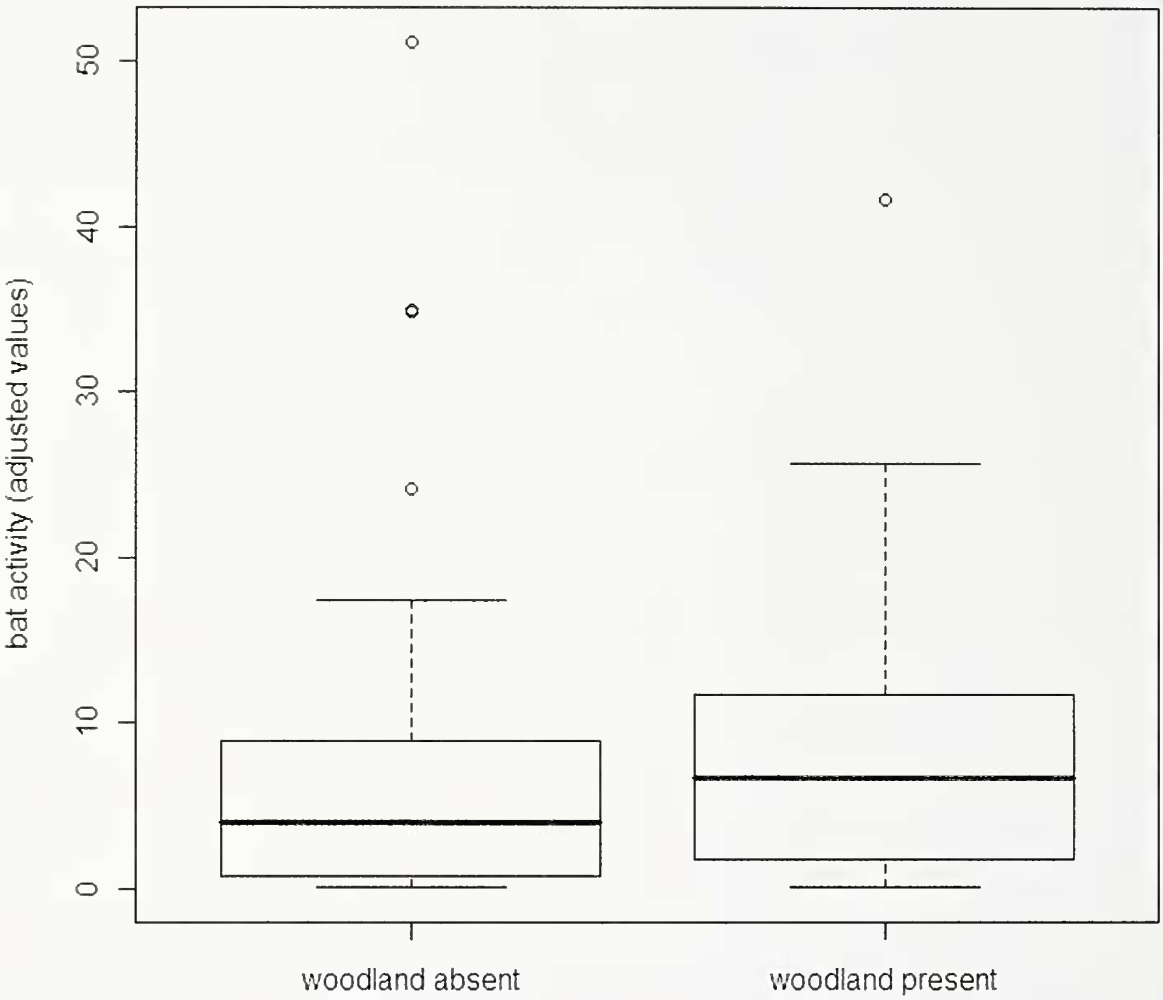

Fig. 2. Adjusted values of total bat passes at ten-minute point counts adjacent (n=50) and not adjacent (n=61) to woodland. Values shown are those corrected for explanatory variables in the final model (Table 2). Tukey box plots are used here with boxes representing the location of the middle 50 percent of the data and the upper and lower quartiles, and the whiskers 1.5 x the interquartile range.

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Urban Biodiversity: Successes and Challenges: Parklife; cities for people and nature

Scott Ferguson

Scottish Natural heritage

Some have argued that suburban gardens are England's most important nature reserve. Can that be true for Scotland too? From the butterfly on the buddleia to the raven nesting on the gas–tower, there is no doubt that the mosaic of habitats across urban areas support an amazing array of wildlife – and offer a wealth of opportunities for people to enjoy, learn about and celebrate that diversity.

Urban Biodiversity: Successes and Challenges: Cities deserve landscape-scale wildlife spectacles

Stuart Housden

Royal Society for the Protection of Birds Scotland

In such uncertain financial times it is heartening to recognise that the policy framework for delivering large scale habitat creation projects in Scotland has never been more positive. This is a recognition that these types of projects have been delivered elsewhere in the UK bringing with them not just a huge boost to biodiversity but a whole brigade of associated benefits.

Whether you are interested in education, climate change, flood alleviation, economic growth, creating a pleasant environment for people to live and work, direct employment or improving the social esteem of previously marginalised communities there is little doubt that investment in landscape scale environmental projects in an urban setting can and should make a significant contribution to the future of Scotland.

Urban Biodiversity: Successes and Challenges: A tactical approach

Malcolm Muir

Countryside and Greenspace Manager, South Lanarkshire council

The quality of urban open spaces can have a significant effect on their neighbouring communities. They offer opportunities for play, healthy recreation, sustainable transport and biodiversity and may indeed be the key to effecting a transformation in public understanding for and engagement with the natural heritage in Scotland. The eco–system approach rightly advocates acceptance of change, decentralisation and the participation of all sectors of society. Greenspaces, largely owned by Local Authorities offer the perfect test bed for this approach and the opportunity to clearly demonstrate to policy makers the links between environmental quality, health and economic and social well being. The current financial "crisis" actually presents a window of opportunity for this area of work but, despite these opportunities, real challenges remain; many of them linked to fundamental public service processes and "mind sets", and these will not be overcome through legislation alone.